

Physics Programme of PANDA at FAIR

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Abstract

The standard model and Quantum Chromodynamics (QCD) have undergone rigorous tests at distances much shorter than the size of a nucleon. Up to now, the predicted phenomena are reproduced rather well. However, at distances comparable to the size of a nucleon, new experimental results keep appearing which cannot be described consistently by effective theories based on QCD. The physics of strange and charmed quarks holds the potential to connect the two energy domains, interpolating between the limiting scales of QCD. This is the regime which will be explored using the future Antiproton Annihilations at Darmstadt (PANDA) experiment at the Facility for Antiproton and Ion Research (FAIR).

In this contribution some of the most relevant physics topics are detailed; and the reason why PANDA is the ideal detector to study them is given. Precision studies of hadron formation in the charmonium region will greatly advance our understanding of hadronic structure. It may reveal particles beyond the two and three-quark configuration, some of which are predicted to have exotic quantum numbers in that mass region. It will deepen the understanding of the charmonium spectrum, where unpredicted states have been found recently by the B-factories. To date the structure of the nucleon, in terms of parton distributions, has been mainly investigated using scattering experiments. Complementary information will be acquired measuring electromagnetic final states at PANDA.

Key words: PANDA experiment, antiproton, charmonium physics, exotic particles
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The physics of strange and charmed quarks holds the potential to connect the energy domains of perturbative Quantum Chromo Dynamics (pQCD) and “effective” theories describing the properties of nucleons, interpolating between the limiting scales of QCD. In this regime only scarce experimental data is available, most of which has been obtained with electromagnetic probes.

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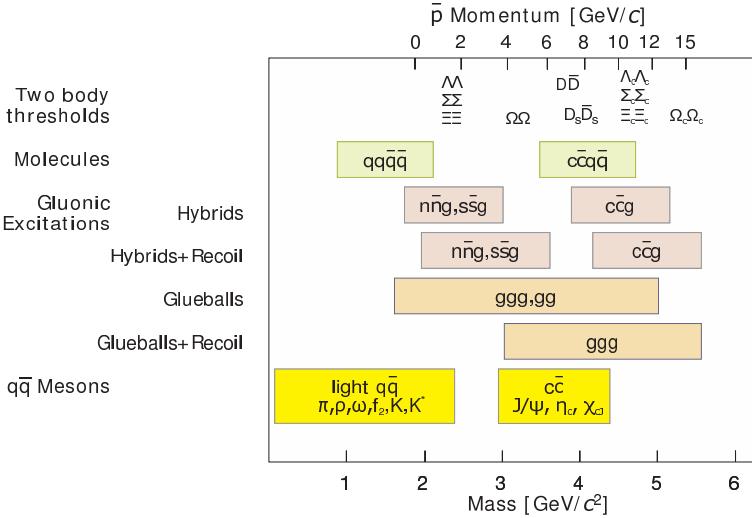


Fig. 1. Mass range of hadrons that will be accessible at PANDA. The upper scale indicates the corresponding antiproton momenta required in a fixed-target experiment. The HESR will provide 1.5 to 15 GeV/c antiprotons, which will allow charmonium spectroscopy, the search for charmed hybrids and glueballs, the production of D meson baryon pairs for pairs and the production of hypernuclear studies.

One possible single issue that may greatly advance our understanding of hadronic structure is the predicted existence of states outside of the two- and three-quark classifications, which for example could arise from the excitation of gluonic degrees of freedom. Recent findings from running experiments at B-factories (see *e.g.* Refs [1]) show that, indeed, unexpected narrow states unaccounted for in the naïve quark models exist. Experiments focussed on the abundant production and systematic studies of these states are needed. Preferably, these should be performed using hadronic probes because the cross sections are expected to be very large in such systems. Results of high precision are a decisive element to be able to identify and extract features of these exotic states. Hadron beams are advantageous also for the production of hadrons with non-exotic quantum numbers, as these can be formed directly with high cross sections. Phase space cooling of the antiproton beam furthermore allows high precision determination of the mass and width of such states. Using heavier nuclei as targets enables us to investigate in-medium properties of hadrons and to produce hypernuclei, even those containing more than one strange quark, copiously.

The PANDA (Antiproton Annihilation at Darmstadt) experiment (see also Ref. [2]), which will be installed at the High Energy Storage Ring for antiprotons of the upcoming Facility for Antiproton and Ion Research (FAIR) [3], features a scientific programme devoted to the following key areas.

- Charmonium spectroscopy.
- Exotic hadrons (hybrids, glueballs, multi-quark states).
- Hadron properties in the nuclear medium.
- Strange and charmed baryons.
- γ -ray spectroscopy of hypernuclei.
- Structure of the nucleon.

Selected other topics will be studied with unprecedented accuracy.

Conventional as well as exotic hadrons can be produced by a range of different experimental means. Among these, hadronic annihilation processes, and in particular antiproton-nucleon and antiproton-nucleus annihilations, have proven to possess all the necessary ingredients for fruitful harvests in the hadron field.

- Hadron annihilations produce a gluon-rich environment, a fundamental prerequisite to copiously produce gluonic excitations.
- The use of antiprotons permits to directly form all states with non-exotic quantum numbers (formation experiments). Ambiguities in the reconstruction are reduced and cross sections are considerably higher compared to producing additional particles in the final state (production experiments). The appearance of states in production but not in formation is a clear sign of exotic physics.
- Narrow resonances, such as charmonium states, can be scanned with high precision in formation experiments using the small energy spread available with antiproton beams (cooled to $\Delta p/p = 10^{-5}$).
- Since exotic systems will appear only in production experiments the physics analysis of Dalitz plots becomes important. This requires high-statistics data samples. Thus, high luminosity is a key requirement. This can be achieved using an internal target of high density, large numbers of projectiles and a high count-rate capability of the detector. The latter is mandatory since the overall cross sections of hadronic reactions are large while the cross sections of reaction channels of interest may be quite small.
- As reaction products are peaked around angles of 0° a fixed-target experiment with a magnetic spectrometer is the ideal tool. At the same time a 4π coverage is mandatory to be able to study exclusive reactions with many decay particles. The physics topics as summarised in Fig. 1 confirm that the momentum range of the antiproton beam should extend up to $15 \text{ GeV}/c$ with luminosities in the order of $10^{32} \text{ cm}^{-2}\text{s}^{-1}$

The PANDA collaboration is prepared to address these topics with a general-purpose internal-target experiment utilising the antiprotons provided at the upcoming FAIR facility (see also Refs. [4,2]). Within the growing PANDA collaboration of currently about 400 physicists from 16 countries, an extensive R&D programme is under way, which comprises already a detailed design of the detector. PANDA gratefully acknowledges the support of the respective national research agencies and the European Union funds.

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